



SPECIFICATION

TO ALL WHOM IT MAY CONCERN:

BE IT KNOWN THAT WE, Seiji Tanuma, a citizen of Japan residing at Kawasaki-shi, Kanagawa, Japan, Yohei Nakanishi, a citizen of Japan residing at Kawasaki-shi, Kanagawa, Japan and Takatoshi Mayama, a citizen of Japan residing at Kawasaki-shi, Kanagawa, Japan have invented certain new and useful improvements in

LIQUID CRYSTAL DISPLAY DEVICE OPERATING IN A
VERTICALLY ALIGNED MODE OF LIQUID CRYSTAL MOLECULES

of which the following is a specification : -

1 TITLE OF THE INVENTION

LIQUID CRYSTAL DISPLAY DEVICE OPERATING IN A
VERTICALLY ALIGNED MODE OF LIQUID CRYSTAL MOLECULES

5 BACKGROUND OF THE INVENTION

The present invention generally relates to
liquid crystal display devices and more particularly
to a high-contrast liquid crystal display device
characterized by a fast response speed and a low
10 electric power consumption.

FIG.1 shows the construction of a
conventional liquid crystal display device of the so-
called TN-mode.

Referring to FIG.1, the conventional liquid
15 crystal display device includes a glass substrate 2a
carrying thereon a number of active devices including
pixel electrodes 6 and cooperating bus lines 5,
wherein the glass substrate 2a faces a glass substrate
2b carrying thereon an opposing electrode 3, with a
20 liquid crystal layer 1 interposed between the glass
substrate 2a and the glass substrate 2b. It should be
noted that the glass substrate 2a further carries a
molecular alignment film 4 so as to cover the
foregoing active devices, while the glass substrate 2b
25 carries another molecular alignment film 5 so as to
cover the opposing electrode 3.

In the conventional structure of FIG.1, a
liquid crystal called TN (twist-nematic) type is used
commonly for the liquid crystal layer 1. In such a
30 conventional, TN-mode liquid crystal display device
using a TN-type liquid crystal, the liquid crystal
molecules are aligned generally parallel to the plane
of the substrates in the non-activated state thereof
in which no drive voltage is applied to the liquid
35 crystal layer. In the non-activated state, the liquid
crystal molecules are further twisted between the
substrate 2a and the substrate 2b with a twist angle

1 of 90°. When a drive voltage is applied to the liquid
crystal layer 1, on the other hand, the liquid crystal
molecules are aligned generally perpendicular to the
plane of the substrates 2a and 2b.

5 Such a TN-mode liquid crystal display device
is used commonly in various information processing
apparatuses. Further, low-cost fabrication process of
such a TN-mode liquid crystal display device is well
established by now.

10 On the other hand, a TN-mode liquid crystal
display device generally has a drawback in that the
contrast ratio of represented images changes
substantially depending on the viewing angle. While
there are various attempts to improve the viewing
15 angle characteristic of TN-mode liquid crystal display
devices, it has been still difficult to realize a
viewing characteristic comparable to that of a CRT
display device.

On the other hand, there is another type of
20 liquid crystal display device in which the liquid
crystal molecules are aligned generally
perpendicularly to the plane of the glass substrate.
In such vertically aligned liquid crystal display
devices, the liquid crystal molecules are aligned
25 generally perpendicular to the plane of the glass
substrates in the non-activated state.

FIGS.2A and 2B show the construction of one
type of such a vertically aligned liquid crystal
display device.

30 Referring to FIG.2A showing a pixel of such
a vertically aligned liquid crystal display device in
the non-activated state thereof, the liquid crystal
display device includes a first glass substrate 10
carrying thereon a pair of electrodes 11a and 11b and
35 a second glass substrate 12 facing the first glass
substrate 10, and a liquid crystal layer 14 is
sandwiched between the glass substrate 10 and the

1 glass substrate 12. In the non-activated state of the
liquid crystal display device, it should be noted that
no drive voltage is applied across the electrodes 11a
and 11b.

5 The liquid crystal layer 14 includes liquid
crystal molecules 16, wherein the liquid crystal
molecules 16 are aligned generally perpendicularly to
the plane of the substrate 10 in the non-activated
state of the liquid crystal display device represented
10 in FIG.2A. It should be noted that the surface of the
substrate 10 on which the electrodes 11a and 11b are
provided is covered by a molecular alignment film not
illustrated. Similarly, the surface of the substrate
12 facing the liquid crystal layer 14 is covered by a
15 molecular alignment film not illustrated. Further, a
pair of polarizers not illustrated are disposed at
respective outer-sides of the glass substrate 10 and
the glass substrate 12.

In the activated state represented in FIG.2B
20 in which a drive voltage is applied across the
electrodes 11a and 11b, on the other hand, the liquid
crystal molecules 16 are aligned in the direction of
the electric field inside the liquid crystal layer 14.
Thereby, the pixel represented in FIG.2B is divided
25 into a first region at a first side of a line A-A' and
a second region at a second, opposite side of the line
A-A', wherein it can be seen that the liquid crystal
molecules 16 are tilted in respective, mutually
opposite directions in the first region and in the
30 second region. As a result of such a subdivision of
the pixel, the liquid crystal display device provides
an excellent viewing angle characteristic.

On the other hand, the vertically aligned
liquid crystal display device of FIG.2 has a drawback
35 in that it requires a drive voltage of at least 5 V.
In order to reduce the power consumption of the liquid
crystal display device, it is desired to reduce the

1 drive voltage.

In a liquid crystal display device, the drive voltage is generally reduced by increasing the retardation value $\Delta n \cdot d$, wherein Δn represents the
5 birefringence and d represents the cell thickness. On the other hand, there has been little information about the optimum value for the birefringence Δn or for the cell thickness d in this type of the vertically aligned liquid crystal display devices.

10 Further, this type of vertically aligned liquid crystal display devices have conventionally suffered from the problem of poor response speed. This drawback becomes particularly conspicuous when performing a motion picture representation.

15

SUMMARY OF THE INVENTION

Accordingly, it is a general object of the present invention to provide a novel and useful liquid crystal display device wherein the foregoing problems
20 are eliminated.

Another object of the present invention is to provide a liquid crystal display device, comprising:

- 25 a first substrate;
- a second substrate facing said first substrate;
- a liquid crystal layer interposed between said first and second substrates; and
- 30 a group of electrodes disposed on said first substrate so as to create an electric field in said liquid crystal layer generally parallel to said first substrate in an activated state in which a drive voltage is applied to said group of electrodes;
- 35 said liquid crystal molecules aligning generally perpendicularly to a plane of said first substrate in a non-activated state in which said drive voltage is not applied to said group of electrodes,

1 said liquid crystal molecules aligning generally
parallel to said plane of said first substrate in said
activated state;

5 said liquid crystal molecules having a pre-
tilt angle of less than 90° in at least one of a part
of said liquid crystal layer corresponding to a pixel
and said electrode on said first substrate.

 According to the present invention, the
response speed of the liquid crystal display device is
10 improved by locally setting the pre-tilt angle of the
liquid crystal molecules to be less than 90° .

 Thereby, such pre-tilted liquid crystal molecules act
as a nuclei when a drive electric field is applied to
the liquid crystal layer, and the tilting of the
15 liquid crystal molecules propagates rapidly throughout
the liquid crystal layer, starting from such a site of
the pre-tilted molecules. Associated with this, the
drive voltage of the liquid crystal display device is
reduced, and hence the electric power consumption.

20 Other objects and further features of the
present invention will become apparent from the
following detailed description when read in
conjunction with the attached drawings.

25 BRIEF DESCRIPTION OF THE DRAWINGS

 FIG.1 is a diagram showing the construction
of a conventional TN-mode liquid crystal display
device;

30 FIGS.2A and 2B are diagrams showing the
construction of a conventional vertically aligned
liquid crystal display device respectively in a non-
activated state and in an activated state thereof;

 FIG.3 is a diagram showing the principle of
the liquid crystal display panel of the present
35 invention;

 FIG.4 is another diagram showing the
principle of the liquid crystal display panel of the

1 present invention;

FIG.5 is a diagram showing the construction of a liquid crystal display device according to a first embodiment of the present invention;

5 FIG.6 is a diagram showing the construction of a liquid crystal display device according to a second embodiment of the present invention;

FIG.7 is a diagram showing the construction of a liquid crystal display device according to a third embodiment of the present invention;

10 FIG.8 is a diagram showing the construction of a liquid crystal display device according to a fourth embodiment of the present invention; and

FIG.9 is a diagram showing the construction of a liquid crystal display device according to a fifth embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[PRINCIPLE]

20 First, the principle of the present invention will be explained with reference to FIG.3 and FIG.4, wherein those parts corresponding to the parts described previously are designated by the same reference numerals and the description thereof will be omitted.

25 Referring to FIG.3, the electrodes 11a and 11b are formed on the first substrate 10, and the first substrate 10 and the second substrate 12 sandwich therebetween a liquid crystal layer 18. As represented in FIG.3, the liquid crystal layer 18 contains liquid crystal molecules 18a, wherein each of the liquid crystal molecules 18a is provided with a pre-tilt angle 20 with respect to the substrate 12 and hence the substrate 10.

35 According to a first aspect of the present invention, the liquid crystal molecules are easily tilted in the pre-tilt direction when the drive

1 voltage is applied across the electrodes 11a and 11b
and the liquid crystal display device is activated.
Associated therewith, the response speed of
representation of the liquid crystal display device is
5 improved. Further, the drive voltage is reduced
substantially and hence the electric power
consumption.

FIG.4 shows irradiation of the molecular
alignment film 4 covering the surface of the glass
10 substrate 10 with a ultraviolet beam 7 according to a
second aspect of the present invention.

As a result of exposure of the molecular
alignment film to an ultraviolet radiation, the
desired pre-tilt angle is provided to the liquid
15 crystal molecules. Further, such an exposure of the
molecular alignment film to the ultraviolet radiation
7 causes a decrease in the specific resistance of the
liquid crystal layer 18, and the electric charges on
the substrate surface are quickly dissipated.
20 Thereby, the liquid crystal display device becomes
substantially free from sticking of images and the
quality of image representation is improved.

Further, there is a third aspect of the
present invention in which the desired decrease of the
25 drive voltage and electric power consumption is
achieved by choosing the liquid crystal constituting
the liquid crystal layer 18 or by setting the
thickness d of the liquid crystal layer 18 such that
the retardation value $\Delta n \cdot d$ is increased as much as
30 possible.

[FIRST EMBODIMENT]

FIG.5 shows a liquid crystal display device
30 according to a first embodiment of the present
35 invention in a cross-sectional view.

Referring to FIG.5, the liquid crystal
display device 30 includes a first glass substrate 32

1 carrying thereon electrodes 34 and 36, wherein it
should be noted that the electrodes 34 and 36 carry
thereon organic projections 38 and 39 respectively.
Further, the first glass substrate 32 is covered by a
5 molecular alignment film 42 such that the molecular
alignment film 42 covers the electrodes 34 and 36 and
further the projections 38 and 39. Further, another
molecular alignment film 44 covers the surface of a
second glass substrate 33. The first glass substrate
10 32 and the second glass substrate 33 are disposed such
that a liquid crystal layer 50 is sandwiched
therebetween. Thereby, the molecular alignment films
42 and 44 restrict the direction of the liquid crystal
molecules in the liquid crystal layer 50 such that the
15 liquid crystal molecules are aligned generally
perpendicularly to the plane of the substrate 32 or 33
in the non-activated state of the liquid crystal
display device 30. In other words, the molecular
alignment films 42 and 44 are vertically aligning
20 molecular alignment films.

The liquid crystal display device 30 of
FIG.5 is fabricated according to the process as
follows.

First, the electrodes 34 and 36 are formed
25 on the first glass substrate 31 by a patterning
process of a conductor layer such that each of the
electrodes 34 and 36 has a width W of $5\text{ }\mu\text{m}$ and such
that the electrodes 34 and 36 are separated from each
other by a mutual separation L of about $12\text{ }\mu\text{m}$.

30 Next, the projections 38 and 39 are formed
respectively on the electrodes 34 and 36 in the form
of a resist pattern having a height h of about $1.5\text{ }\mu\text{m}$.
After applying a thermal curing process to the resist
pattern thus formed at the temperature of about 120°C
35 for about 30 minutes, each of the projections 38 and
39 undergoes a reflowing, and the resist projections
38 and 39 are transformed to have a bell-shaped form.

1 Next, the vertically aligning molecular
alignment film 42 is formed on the glass substrate 32
so as to cover the electrodes 34 and 36. Similarly,
the vertically aligning molecular alignment film 44 is
5 formed on the inner surface of the glass substrate 33.
The substrates 32 and 33 are then assembled such that
the molecular alignment films 42 and 44 face with each
other with a separation d of about 9 μm .

10 Further, polarizers 46 and 48 are disposed
on respective outer surfaces of the first glass
substrate 32 and the second glass substrate 33 such
that the optical absorption axis of the polarizer 46
cross perpendicularly the optical absorption axis of
th polarizer 48. Further, the liquid crystal layer 50
15 is confined into the gap thus formed between the
substrate 32 and the substrate 33.

20 As represented in FIG.5, the liquid crystal
molecules in the liquid crystal layer 50 are aligned
vertically to the plane of the substrate 32 or 33 in
the non-activated state of the liquid crystal display
device 30, except for those liquid crystal molecules
adjacent to the foregoing bell-shaped projections 38
and 39.

25 In view of the nature of the vertically
aligning molecular alignment film 42, it should be
noted that the liquid crystal molecules maintain a
generally vertical relationship with respect to the
molecular alignment film 42, including the liquid
crystal molecules 50a and 50b that are located
30 adjacent to the projection 38 or the projection 39.
Thereby, the liquid crystal molecule 50a or 50b form
an oblique, pre-tilt angle 51 with respect to the
substrate 32, wherein it should be noted that the
direction of the pre-tilt angle 51 is identical with
35 the general direction of tilting of the liquid crystal
molecules when a drive voltage is applied across the
electrodes 34 and 36. Thus, when a drive voltage is

1 applied across the electrodes 34 and 36, the liquid
crystal molecules in the liquid crystal layer 50 is
influenced by the pre-tilt direction of the liquid
crystal molecules 50a and 50b and undergo a tilting in
5 the same direction as the pre-tilt direction of the
liquid crystal molecules 50a and 50b. Such a tilting
of the liquid crystal molecules propagates to other
liquid crystal molecules in the liquid crystal layer
50 rapidly.

10 Thus, the liquid crystal molecules 50a and
50b determine the tilting direction of the liquid
crystal molecules in the liquid crystal layer 50 when
a drive voltage is applied to the electrodes 34 and
36. Thereby, the time needed for the entire liquid
15 crystal molecules in the liquid crystal layer 50 to
undergo the tilting is substantially reduced.

In the event the pre-tilted liquid crystal
molecules 50a or 50b were not present, on the other
hand, it would take a longer time until the entire
20 liquid crystal molecules undergo tilting as
represented in the state of FIG.2A because of the lack
of the factor that determines the initial direction of
the tilting. Associated with this, the drive voltage
necessary for driving the liquid crystal display
25 device 30 would increase. Thereby, the electric power
necessary for driving the liquid crystal display
device 30 would increase also.

As noted above, the pre-tilting of the
liquid crystal molecules 50a and 50b effectively
30 reduces the time and magnitude of the electric field
necessary for causing the tilting of the entire liquid
crystal molecules in the liquid crystal layer 50.

Table 1 below compares the performance of
the liquid crystal display device 30 with the
35 performance of a conventional vertically aligned
liquid crystal display device in which no such a
projection is provided, wherein it should be noted

1 that Table 1 compares the saturation voltage and
response time needed for the liquid crystal display
device to reach a predetermined transmittance.

5 TABLE 1

	saturation voltage	response time [ms] on/off
10 conventional	5.0 V	25/38
1st embodiment	4.3 V	23/37

15 Table 1 clearly indicates the decrease of
the saturation voltage in the present embodiment in
which the projections 38 and 39 are formed over the
conventional device. This means that the voltage
needed for driving the liquid crystal display device
30 is reduced over the conventional device. Further,
20 the response time is improved over the conventional
device. It should be noted that a saturation voltage
is a voltage needed for a liquid crystal display
device to achieve a predetermined transmittance.

25 [SECOND EMBODIMENT]

Next, a liquid crystal display device 31
according to a second embodiment of the present
invention will be described with reference to FIG.6,
wherein those parts corresponding to the parts
30 described previously are designated by the same
reference numerals and the description thereof will be
omitted.

Referring to FIG.6, it can be seen that the
liquid crystal display device 31 has a construction
35 similar to that of the liquid crystal display device
30 of the previous embodiment, except that there is
formed a projection 41 also on the second glass

1 substrate 33.

The projection 41 may be formed as a resist pattern prior to the step of forming the molecular alignment film 44 on the substrate 33 such that the projection 41 faces the opposing glass substrate 32. Typically, the resist pattern forming the projection 41 is formed with a height h of about $1.5\text{ }\mu\text{m}$, similarly to the resist patterns forming the projections 38 and 39. After formation of the resist pattern 41, a thermal curing process is applied before providing the molecular alignment film 44. Thereby, the resist pattern 41 undergoes a reflowing to form a bell-shaped projection similarly to the projections 38 and 39. Thereafter, the molecular alignment film 44 is provided on the glass substrate 33 so as to cover the projection 41.

By providing the projection 41, the liquid crystal molecules 50c and 50d adjacent to the projection 41 are provided with the pre-tilt angle 51, and the pixel region is divided into a first region 52 located at a first side of the projection 41 and a second region 54 located at a second side of the projection 41. In the first region 52, the direction of tilting of the liquid crystal molecule 50c is generally the same with the direction of tilting of the liquid crystal molecule 50a. Similarly, the direction of tilting of the liquid crystal molecule 50d is generally the same with the direction of tilting of the liquid crystal molecule 50b in the second region 54. Thus, the tilting of the liquid crystal molecules in the liquid crystal layer 50 in the activated state of the liquid crystal display device 31 is substantially facilitated and a further reduction of the drive voltage and a further increase of the response speed are achieved.

Table 2 below represents the performance of the liquid crystal display device 31 of the present

1 embodiment in comparison with the performance of the
conventional vertically aligned liquid crystal display
device noted in Table 1.

5 TABLE 2

	saturation voltage	response time [ms] on/off
10 conventional	5.0 V	25/38
2nd embodiment	3.8 V	20/36

As is expected, the liquid crystal display
15 device 31 of the present embodiment shows a reduced
saturation voltage and increased response speed over
the conventional vertically aligned liquid crystal
display device having no such projections. The result
of TABLE 2 further indicates that the addition of the
20 projection 41 in addition to the projections 38 and 39
further improves the performance of the liquid crystal
display device.

[THIRD EMBODIMENT]

25 FIG.7 shows the construction of a liquid
crystal display device 60 according to a third
embodiment of the present invention.

Referring to FIG.7, the liquid crystal
display device 60 includes a first glass substrate 62
30 carrying thereon electrodes 64 and 66, wherein the
electrodes 64 and 66 carry thereon projections 68 and
69 respectively. Further, the first glass substrate
62 is covered by a molecular alignment film 72 wherein
the molecular alignment film 72 is formed so as to
35 cover the electrodes 64 and 66.

Further, the liquid crystal display device
60 includes a second glass substrate 63 carrying

1 thereon a projection 71, wherein the second glass
substrate 63 including the projection 71 is covered by
a molecular alignment film 74.

5 The first and second substrates 62 and 63
are disposed so as to sandwich a liquid crystal layer
70 therebetween, and polarizers 78 and 77 are disposed
at respective outer-sides of the substrates 62 and 63.

 The liquid crystal display device 60 of
FIG.7 is fabricated as follows.

10 First, the electrodes 64 and 66 are formed
on the first substrate 62 by a patterning process of a
conductive layer, and the projections 68 and 69 are
formed respectively on the electrodes 64 and 66 in the
form of a resist pattern. Further, the projection 71
15 is formed on the substrate 63 also in the form of a
resist pattern.

 The resist patterns thus formed for the
projections 68 and 69 or the projection 71 are then
subjected to a thermal curing process together with
20 the substrate 62 or 63, wherein the resist patterns
undergo a reflowing during such a thermal curing
process, and the projections 68 and 69 and the
projection 71 are formed to have a bell-shaped form.

 After the formation of the projections 68
25 and 69 as mentioned above, the surface of the
substrate 62 carrying the projections 68 and 69 is
covered by the molecular alignment film 72.
Similarly, the surface of the substrate 63 carrying
the projection 71 is covered by the molecular
30 alignment film 74. The substrates 62 and 63 thus
prepared are assembled to form a liquid crystal cell,
and the liquid crystal layer 70 is confined between
the space formed between the substrates 62 and 63.

 In the present embodiment, the liquid
35 crystal display device thus fabricated is subjected to
an ultraviolet exposure process similar to that of
FIG.4, wherein the molecular alignment films 72 and 74

1 are exposed to a ultraviolet radiation before the
substrates 62 and 63 are assembled.

5 More in detail, the ultraviolet exposure
process is conducted twice, first from a first
direction and next from a second, opposite direction
while protecting the right-side part of the projection
71 of the liquid crystal cell by a mask (not shown)
during the first exposure process and while protecting
the left-side part of the projection 71 of the liquid
10 crystal cell by another mask (not shown) during the
second exposure process.

By applying a ultraviolet radiation to the
molecular alignment films 72 and 74 as noted above,
15 the liquid crystal molecules in the liquid crystal
layer 70 are tilted with a tilt angle 76, wherein the
foregoing exposure process is optimized such that the
liquid crystal molecules are tilted in the same
tilting direction of the projection 68 or 71 in the
or 70c adjacent to the projection 71 and such that the
20 left-side part of the projection 68 or 71 in the
liquid crystal molecules are tilted in the same
tilting direction of the projection 71
or 70d adjacent to the projection 69 or 71 in the
right-side part of the projection 71. Thereby, the
25 liquid crystal molecules in the liquid crystal layer
70 at the left-side part of the projection 71
generally have the same tilt angle 76 in a first
tilting direction, while the liquid crystal molecules
30 at the right-side part of the projection 71 generally
have the same tilt angle in the opposite tilting
direction.

By conducting the ultraviolet exposure
process with a dose of about 1.5 J/cm^2 with the angle
of the ultraviolet beam set to 45° as represented in
35 FIG.4, an angle of about 89° is realized for the tilt
angle 76 of the liquid crystal molecules. As the
liquid crystal molecules are thus tilted generally

1 uniformly in the respective tilting directions
throughout the right-side part or left-side part of
the projection 71 in the liquid crystal layer 70, the
tendency of the liquid crystal molecules to cause a
5 tilting upon application of a driving electric field
to the liquid crystal layer 70 is enhanced further.

Table 3 below represents the saturation
voltage and response time for the liquid crystal
display device 60 of the present embodiment.

10

TABLE 3

	saturation voltage	response time [ms] on/off
15		
conventional	5.0 V	25/38
3rd embodiment	4.1 V	22/37

20 As can be seen in Table 3, the liquid
crystal display device 60 of the present embodiment
has the saturation voltage and response time improved
substantially over the conventional vertically aligned
liquid crystal display device.

25 In the present embodiment, there is a
further advantageous feature, associated with the
ultraviolet exposure process, in that such an
ultraviolet radiation reduces the resistance of the
liquid crystal layer 70. More specifically, such a
30 ultraviolet radiation effectively eliminates the
electric charges accumulated between the liquid
crystal layer 70 and the molecular alignment film 72
or 74 and the quality of image representation is
improved.

35

[FOURTH EMBODIMENT]

Next, a liquid crystal display device 80

1 according to a fourth embodiment of the present
invention will be described with reference to FIG.8.

Referring to FIG.8, the liquid crystal
display device 80 includes a first glass substrate 82
5 carrying thereon electrodes 84 and 86, wherein the
surface of the glass substrate 82 carrying the
electrodes 84 and 86 is covered by a molecular
alignment film 91 including the electrodes 84 and 86.
Further, the liquid crystal display device 80 includes
10 a second glass substrate 83 covered by another
molecular alignment film 92.

The glass substrate 82 and the glass
substrate 83 are assembled such that the surface of
the substrate 82 carrying the molecular alignment film
15 91 faces the surface of the substrate 83 carrying the
molecular alignment film 92, and a liquid crystal
layer 88 is confined in the space formed between the
glass substrates 82 and 83 thus assembled. Further,
there are provided polarizers 93 and 94 at respective
20 outer-sides of the glass substrates 82 and 83.

In the present embodiment, the formation of
projections used in the previous embodiments is
eliminated by selecting the material of the liquid
crystal layer 88. Further, the present embodiment
25 eliminates the process of ultraviolet radiation. More
specifically, the liquid crystal display device 80 of
the present embodiment achieves the desired decrease
of driving voltage and power consumption by optimizing
the material of the liquid crystal layer 88 and the
30 cell structure of the device 80 such that the
retardation value $\Delta n \cdot d$ is maximized.

The simplest answer to increase the
retardation value $\Delta n \cdot d$ would be to increase the cell
thickness d as large as possible. However, such an
35 increase in the cell thickness d tends to invite a
deterioration in the response speed. In order to
increase the retardation value $\Delta n \cdot d$ while

1 simultaneously suppressing the increase of the cell
thickness d , therefore, it is necessary to choose a
liquid crystal material having a large birefringence
 Δn for the liquid crystal layer 88.

5 The requirement for the birefringence Δn of
the liquid crystal layer 88 is as follows.

In view of the maximum allowable value of
the cell thickness d , which is determined from the
desired response speed of the liquid crystal display
10 device 80, the liquid crystal layer 88 is required to
have a birefringence Δn of larger than about 0.15. On
the other hand, in view of the practical lower limit
value of the cell thickness d of about 3 μm , which
lower limit value being determined by the fabrication
15 technology used for mass producing the liquid crystal
display device 80, the liquid crystal layer 88 is
required to have a birefringence Δn of smaller than
0.25.

Thus, the liquid crystal material forming
20 the liquid crystal layer 88 should have a
birefringence Δn satisfying the relationship (1)

$$0.15 < \Delta n \cdot d < 0.25. \quad (1)$$

25 The relationship (1) is satisfied by using a
liquid crystal containing a tolan-family component.
Generally, a tolan-family liquid crystal has a low
resistance and is advantageous for dissipating static
electric charges. Thereby, a high-quality image
30 representation free from sticking of the images is
achieved easily.

In the liquid crystal display device 80 of
the present embodiment, a liquid crystal having a
birefringence Δn of 0.202 ($\Delta n = 0.202$) is used in
35 combination with a cell thickness d of 3.5 μm ($d = 3.5$
 μm), wherein the liquid crystal has a dielectric
anisotropy $\Delta\epsilon$ of 5.8 ($\Delta\epsilon = 5.8$). In the liquid

1 crystal device 80, each of the electrodes 84 and 86
has a width W of 5 μm , wherein the electrodes 84 and
86 are separated from each other by a distance L of 12
5 μm . As noted already, the liquid crystal display
device 80 includes no projections. Further, there is
no exposure process to ultraviolet radiation in the
fabrication process of the liquid crystal display
device 80.

10 Table 4 below compares the performance of
the liquid crystal display device 80 thus formed with
the conventional vertically aligned liquid crystal
display device.

TABLE 4

15		saturation voltage	response time [ms] on/off
	conventional	5.0 V	25/38
20	4th embodiment	5.1 V	15/20

Referring to Table 4, it can be seen that
the response time is reduced substantially over any of
25 the conventional device or the device of first through
third embodiments, wherein the result of Table 4
indicates that the use of the liquid crystal having a
large birefringence larger than in any of the
foregoing first through third embodiments improves the
30 voltage response characteristic with regard to the
tilting of the liquid crystal molecules.

[FIFTH EMBODIMENT]

35 FIG.9 shows the construction of a liquid
crystal display device 100 according to a fifth
embodiment of the present invention, wherein the
liquid crystal display device 100 has a construction

1 similar to that of the liquid crystal display device
80 of the previous embodiment except that projections
96 and 98 are respectively provided on the electrodes
24 and 86. In FIG.9, those parts corresponding to the
5 parts described previously are designated by the same
reference numerals and the description thereof will be
omitted.

Table 5 below represents the saturation
voltage and response time for the liquid crystal
10 display device 100 of the present embodiment in
comparison with the conventional vertically aligned
liquid crystal display device.

TABLE 5

15		saturation voltage	response time [ms] on/off
	conventional	5.0 V	25/38
20	5th embodiment	4.3 V	9/15

Referring to Table 5, it can be seen that
both the saturation voltage and response time are
25 improved substantially over the conventional device.
Particularly, the improvement of response time is
remarkable. The result of Table 5 indicates that the
combination of the construction of the embodiment of
FIG.8 with the feature of the projections in the first
30 embodiment is highly effective for reducing the
electric power consumption of the liquid crystal
display device.

Further, the present invention is not
limited to the embodiments described heretofore, but
35 various variations and modifications may be made
without departing from the scope of the present
invention.